HUBBLE SPACE TELESCOPE IMAGES OF A SAMPLE OF TWENTY NEARBY LUMINOUS QUASARS [1]

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Received ______________________; accepted ______________________

[1]Based on observations with the NASA/ESA Hubble Space Telescope, obtained at the Space Telescope Science Institute, which is operated by the Association of Universities for Research in Astronomy, Inc., under NASA contract NAS5-26555.

ABSTRACT

Observations with the Wide-Field Camera of the *Hubble Space Telescope (HST)* are presented for a representative sample of 20 intrinsically luminous quasars with redshifts smaller than 0.30. These observations show that luminous quasars occur in diverse environments that include ellipticals as bright as the brightest cluster galaxies (2), apparently normal ellipticals (10), apparently normal spirals with H II regions (3), complex systems of gravitationally interacting components (3), and faint surrounding nebulosity (2).

The quasar host galaxies are centered on the quasar to the accuracy of our measurements, 400 pc. Some of the host galaxies show no evidence of merging or strong gravitational interactions. There are more radio quiet quasars in galaxies that appear to be ellipticals (7) than in spiral hosts (3), contrary to expectations. However, three, and possibly five, of the six radio loud quasars have detectable elliptical hosts, in agreement with expectations. Strong upper limits are placed on the possible existence of optical jets. The luminous quasars studied in this paper occur preferentially in luminous galaxies. The average absolute magnitude of the hosts is 2.2 magnitudes brighter than expected for a field galaxy luminosity function.

The superb optical characteristics of the repaired *HST* make possible the detection of close galactic companions; we detect eight companion galaxies within projected distances of 10 kpc from the quasars. The presence of very close companions, the images of current gravitational interactions, and the higher density of galaxies around the quasars suggest that gravitational interactions play an important role in triggering the quasar phenomenon.

Subject headings: galaxies:clusters:general − quasars:general

1. INTRODUCTION

Figures 1 and 2 tell the main story of this paper. We urge the reader to look at these beautiful *HST* images before continuing with the text and the quantitative details.

We summarize in this paper the results of our analysis of *HST*-WFPC2 observations of a representative sample of 20 of the most luminous ($M_V < -22.9$) nearby ($z < 0.30$) quasars. The goal of these observations was to help understand the quasar phenomenon by determining the environment in which quasars occur. The main result of this paper is that there is not one type of environment, but instead a wide range of environments in which the most luminous quasars appear to be embedded. The *HST* images also contain a number of extraordinary phenomena and some surprises, including: host galaxies that appear normal and show no evidence of strong gravitational interactions, very close galactic companions, host ellipticals for radio quiet quasars, spiral hosts with well developed arms and prominent H II regions, galaxies caught in the act of merging, apparently faint galactic hosts, and very extended emission.

Some partial results of this study have been reported previously: Bahcall et al. (1994, 1995, 1995a,b,c, 1996). For those aspects of the work that depend upon the subtraction of a stellar point spread function (PSF), there are small, quantitative differences between the results described in this paper and previous results we have reported. In the previous work, we used a stellar PSF determined from a red standard star, F141. In the present work, we have used stellar PSFs that were obtained for four separate blue stars (see discussion in Section 4 of the PSFs constructed by Krist and Burrows 1996). The visual appearance of the hosts in the subtracted images is, in a few cases, significantly improved by using the PSFs of the blue stars.

Other *HST* studies of quasar imaging (although many of the objects do not satisfy our luminosity criterion) include Hutchings & Morris (1995), Hutchings et al., (1994), and

Disney et al. (1995).

The subject of quasar environments has a long and distinguished history. Some representative papers that report on ground-based observations are: Kristian (1973), Wyckoff et al. (1980), Wyckoff, Wehinger, & Gehren (1981), Tyson, Baum, and Kreidl (1982) Hutchings et al. (1982), Gehren, et al. (1984), Heckman et al. (1984), Malkan (1984), Malkan, Margon, & Chanan (1984), Boroson, Persson, & Oke (1985), Smith et al. (1986), Hutchings (1987), Stockton & MacKenty (1987), Yee (1987), Hutchings, Janson, & Neff (1989), Romanishin & Hintzen (1989), Véron-Cetty & Woltjer (1990), Hutchings & Neff (1992), Dunlop et al. (1993), and McLeod & Rieke (1994a,b).

The analyses described in these pioneering ground-based studies are made difficult because of atmospheric seeing; the light from the bright central (nuclear) sources may be a few magnitudes brighter than the total emission from the host galaxies. Nevertheless, there is agreement (within typically one magnitude or better) between our *HST* observations and previous ground-based estimates of the total apparent magnitudes of the host emission, although *HST* reveals details not previously accessible and corrects some important conjectures that are not supported by the higher-resolution observations.

The paper is organized as follows. In Section 2 we describe the sample selection and observations; in Section 3 we present the unprocessed data; in Section 4 we describe the method of removing the light due to the quasar (point spread function subtraction) and present the data after a stellar PSF is subtracted; in Section 5 we describe the methods of analysis of the data; in Section 6 we report on the measurements of the host galaxies; in Section 7 we discuss the presence of companion galaxies; in Section 8 we compare our measurements with results from some ground-based observations; in Section 9 we comment on the environment and host galaxy of each quasar, and in Section 10 we summarize and discuss our results. We assume in this paper that $H_0 = 100$ km s^{-1}Mpc^{-1} and $\Omega_0 = 1.0$.

2. SAMPLE SELECTION AND OBSERVATIONS

We describe in this section how the sample was selected (§ 2.1) and how the observations were performed (§ 2.2).

2.1. Sample Selection

A sample of 14 quasars was selected solely on the basis of luminosity ($M_V < -22.9$), redshift ($z \leq 0.20$), and galactic latitude ($|b| > 35°$). All the quasars in the Véron-Cetty & Véron (1991) catalog that satisfied the redshift, luminosity, and galactic latitude criteria were included in this sample; no distinction was made on the basis of radio or other secondary properties. One may choose to call this set of quasars a "complete sample" within the context of the Véron-Cetty & Véron (1991) catalog[2].

The 14 quasars with $z \leq 0.20$ have an average (median) absolute magnitude $\langle M_V \rangle = -23.4$ (23.2) and an average redshift $\langle z \rangle = 0.17$. Only 3 radio loud quasars are present in the original sample of 14 objects. In the Véron-Cetty and Véron (1996) catalog, there are an additional 4 quasars with $z \leq 0.20$ that satisfy our luminosity and galactic latitudes requirements; all are radio quiet.

By combining the time available from GTO and GO programs, an additional 6 quasars

[2]The concept of a "complete" sample of quasars requires clarification since a variety of techniques, including radio emission, optical colors, variability, and x-ray emission, are used to discover quasars. It is conceivable, indeed likely, that there is at least one object satisfying our defining sample criteria that has not yet(in 1996) been recognized observationally. For lack of a better term, we use here the designation "complete sample" in a limited sense to mean all the objects within a specified catalog having stated characteristics.

with redshift between $0.20 < z < 0.30$ were added to the original sample of 14 objects; these additional objects satisfied the same luminosity and galactic latitude constraints as the original sample. The additional objects contain 3 radio loud quasars; the total sample of 20 contains 6 quasars that are classified as radio loud, i.e. with $L_{5\mathrm{GHz}} \gtrsim 10^{26}$ W Hz^{-1} (Kellermann et al. 1994). The additional 6 objects are slightly brighter in the optical on the average (median), $\langle M_V \rangle = -24.0$ (-24.1), and have slightly larger redshifts, $\langle z \rangle = 0.26$. The range of absolute magnitudes in the 6 added objects, $-24.6 \leq M_V < -22.9$, is included within the range of absolute magnitudes spanned by the original sample of 14 objects, i.e., $-25.6 \leq M_V < -22.9$.

In what follows, we shall refer to the total sample of 20 quasars as a "representative sample" with $M_V < -22.9$ and $z < 0.30$. The average (median) absolute magnitude for the full sample is -23.6 (-23.2); the average redshift $\langle z \rangle = 0.19$. Nearly all (18) of the quasars have $15.1 < V < 16.7$, but two are much brighter in the optical band: 3C 273 ($V = 12.8$) and HE 1029−140 ($V = 13.9$).

2.2. Observations

A journal of the observations is given in Table 1, which lists the following quantities for each object: the date observed, the longest exposure time of a single image, the detected number of electrons pixel^{-1} sec^{-1} in the sky, the quasar redshift, the distance in kiloparsecs that corresponds to an angular separation of $1''$ as seen from Earth, the apparent V-magnitude (from Véron-Cetty & Véron 1996), the absolute V-magnitude (without k-correction), the radio properties (an "X" identifies the radio loud quasars), and in the last column the existence of *HST* spectroscopy (a "K" indicates that the *HST*/FOS observations were taken as part of the *HST* Quasar Absorption Line Key Project, and some of the results are reported by Bahcall et al. (1993) and Jannuzi et al. (1997); an "O"

indicates that other FOS observations exist).

The quasars were observed with the Wide Field/Planetary Camera-2 (WFPC2) through the F606W filter, which is similar to the V bandpass but is slightly redder; the mean wavelength and FWHM of the F606W system response are 5935 Å and 1500 Å, respectively. The F606W filter was chosen because of its high throughput. In all of the quasars discussed here, redshifted $H\beta$ and [O III] are included in the bandpass. At a given angular radius, the scattered light in the Wide Field Camera-2 (WF) is about five times less than the scattered light in the Planetary Camera (see Krist & Burrows 1994). We chose to use the WF instead of the PC in the original formulation of this program because of the likelihood that the host galaxies would have low surface brightnesses that extended over areas large compared to the WF resolution ($0.1''$ or about 0.2 kpc). The results reported here support the original choices, since the observed galaxy extensions are indeed large compared to the WF resolution.

The center of light of all quasars was placed within $4'' \pm 1''$ from the center of the Wide-Field Camera CCD 3 (WF3). Three exposures were taken of each quasar. The integration times for 14 objects were 1400 s, 500 s, and 200 s; the exposures for the remaining six objects were 1100 s, 600 s, and 100 s.

The size of WF3 is 800×800 pixels (exposed area $\sim 770 \times 750$ pixels) and its image scale is $0\farcs0996$ pixel^{-1}. We report measured F606W magnitudes on the *HST* photometric scale established by Holtzman et al. (1995b). The adopted photometric zero-point for 1 electron sec^{-1} is 24.94 mag for the F606W filter. For further information about the WFPC2, see Burrows (1994), Trauger et al. (1994), and Holtzman et al. (1995a,b). Additional details of the observational procedures are given in Paper I and Paper II.

The innermost regions of the quasar images are saturated in all of the longest exposures out to a radius $\approx 0.3''$, except for the the two optically brightest quasars in our sample,

HE 1029−140 and 3C 273, in which cases the images were saturated out to $\approx 0.5''$ and $0.7''$, respectively. The number of saturated pixels in the central region of the quasar images were typically 30 pixels for the longest exposures. In addition, ~ 15 saturated pixels were present due to the "vertical bleeding". For HE 1029−140 and 3C 273, the number of saturated pixels was approximately 105 and 190, respectively, plus 90 and 390 from the vertical bleeding.

The initial data processing (bias frame removal and flat-field calibration) was performed at the Space Telescope Science Institute with their standard software package. The individual images of each quasar were aligned to better than 0.3 pixel; this made it easy to identify and eliminate cosmic ray events. Cosmic rays were identified by a pixel-by-pixel comparison of pairs of images; the intensity of a pixel containing a cosmic ray was replaced by the scaled value of the intensity of the pixel in the other image. The flat-field corrections were based upon pre-flight calibrations; these calibrations remove the small-scale (few pixel) sensitivity variations. The typical signal and rms of the noise of the sky in the long exposures (in detected photons per pixel) are 157 and 14, respectively.

The sky level corresponds to an average surface brightness of approximately 22.2 mag arcsec^{-2}. The limiting surface brightness at which objects can be detected is typically between 25 and 26 mag arcsec^{-2} (F606W), cf. Table 2.

3. THE UNPROCESSED IMAGES

We present in this section the images as received from STScI, without further processing except for the removal of cosmic rays.

Figure 1 shows a $23'' \times 23''$ WF image of each of the 20 quasars, plus the image of a blue star (upper left-hand portion). The images displayed are the longest individual

exposures we have. Many, but not all, of the quasars are noticeably non-stellar, and host galaxies are visible on the unprocessed *HST* images. The exposure time of the star image shown in the top panel of Figure 1 is 20 s, which yields a total number of counts similar to that obtained in the quasar images. The star is MMJ 6490 in the M67 cluster. Its apparent V magnitude is 10.99 and its $B - V = 0.11$ (Montgomery, Marschall & Janes 1993).

Some features of host galaxies are obvious in Figure 1. Normal spiral galaxies, with prominent H II regions, envelop PG 0052+251 and PG 1402+261. Host elliptical galaxies are clearly seen in the images of PHL 909, HE 1029−140, PG 1116+215, and 3C 273. There are three obvious cases of current gravitational interaction: 0316−346, PG 1012+008, and PKS 2349−014.

Some of the host galaxies are seen even in our shortest exposures (200 s, see Bahcall et al. 1996 for short exposure images of PG 0052+251 and PHL 909). In some cases, like NAB 0205+02, PG 0953+414, and PG 1307+085, it is difficult to distinguish the quasar image from the star even in our longest exposures.

4. IMAGES AFTER SUBTRACTION OF A STELLAR PSF

The major challenge in the analysis of these *HST* data is the removal of the light produced by the quasar, which is presumed to be a point source. We have adopted an empirical approach. We have used images of stars observed at the same location on the detector as the quasars to determine the point-spread function, PSF, of the stellar quasar.

For about half of the quasars considered here, the principal observational results concerning the host environment can be obtained without the PSF subtraction. Examples of exceptions are the hosts of NAB 0205+02, PG 0953+414, PG 1444+407, and 3C 323.1, which are more apparent in Figure 2 than in Figure 1. Close companions for PKS 1302−102,

PKS 2135−147, and PKS 2349−014 are also more clearly visible after the subtraction of a stellar PSF.

The stellar PSF was measured in Cycle 5 (HST program 5849) by obtaining a set of 13 images for each of four blue stars in the M67 cluster. The calibration stars (and their $B-V$ colors) are: MMJ 6481(−0.073), MMJ 6490(0.11), MMJ 6504(0.22), and MMJ 6511(0.34). The apparent magnitudes range from $V = 10.03$ to $V = 10.99$. For each star, a series of four images were used by Krist and Burrows (1996) to produce a PSF that samples the full dynamic range of the star image and covers the saturation range found in the quasar images. In these calibration images, the radius of the saturated region varies from $0.0''$ to $0.6''$; the exposure times range from 0.1 s to 100 s.

The PSF data are publicly available at http://www.sns.ias.edu/~jnb. There is detailed documentation regarding the PSF data and their use at this site (go to HST Images) by J. Krist and C. Burrows describing how the PSFs were constructed.

Whenever PSF subtractions were required, we used all four PSFs determined by Krist and Burrows. For each case, we selected the result that gave the cleanest subtraction (i.e., the fewest artifacts produced).

We fit a stellar point-spread function to each quasar image and subtracted a multiple of the normalized PSF to search for underlying diffuse light from hosts. The best fit was determined by minimizing the differences between the quasar and the PSF using a χ^2-routine calculated in two distinct areas: azimuthal averages and narrow regions centered on the diffraction spikes. The two methods gave essentially same results (see Paper II), differing in inferred host galaxy magnitude by ± 0.1 mag. The quasar images with the PSF subtracted presented in this paper were obtained by minimizing the χ^2 in azimuthal averages.

We have estimated some of the likely systematic uncertainties in the subtraction process by subtracting a best-fit PSF of the standard star, MMJ 6504, from the image of another standard star, MMJ 6490. We have Cycle 5 observations of MMJ 6490 observed at the same position in WF3 as the sample quasars. Figure 2a (first panel) shows the image of the best fit of MMJ 6504 subtracted from MMJ 6490. The PSF subtraction, star from star, is very good, although some faint diffuse residuals are still present. If we scale the intensity of MMJ 6490 so that the central brightness corresponds to the apparent magnitude of one of our typical quasars, i. e., $V = 15.6$, then the residual "nebulosity" left over when the MMJ 6504 PSF is subtracted is about 21.0 mag.

Figure 2 shows the images for all the quasars in our sample after a best-fit stellar point-spread function (PSF) was subtracted from the original images shown in Figure 1.

Table 2 lists the major diameter of the host galaxies in arcseconds and in kpc, the surface brightness of the isophote for which the size was measured, and a tentative morphological classification. For each quasar, the magnitude of the host galaxy was calculated using three different methods, aperture photometry (see § 5.1), and one-dimensional and two-dimensional galaxy modeling (see § 5.2 and § 5.3).

We determined the size of the quasar hosts by examining the PSF subtracted images and measuring the faintest isophotes of the host galaxy. The morphological classification was done by visual inspection of the images and following as closely as possible the classification given in *The Hubble Atlas of Galaxies* by Sandage (1961). In a number of cases indicated by (?) in Table 2, we have denoted as "En" featureless, smooth hosts that do not show any obvious discontinuities or morphological features.

5. METHODS OF ANALYSIS

In this section, we describe the different methods of analysis that we have used to determine the properties of the quasar hosts. The measured quantities are presented in Tables 2–7 and discussed in §§ 6–7. We describe in §§ 5.1 to 5.3 different methods for estimating the magnitude of the host galaxies. We discuss in § 5.1 our results for aperture photometry, in § 5.2 the radial profile fits, and in § 5.3 the two-dimensional fits.

Some of the host environments are complex, including merging or tidally interacting galaxies and close companions. The smooth de Vaucouleurs or exponential disk models used in § 5.2 and 5.3 are obviously not realistic descriptions of the light distribution for complex environments. In order to provide a common basis of comparison with ground based observations, we provide the results of fits with smooth models for all of the host environments, complex or not.

5.1. Aperture Photometry

We performed aperture photometry in circular annuli centered on the quasars, after a best-fit PSF was subtracted. An inner radius of $r = 1.0''$ was used for all quasars, except for HE 1029$-$140 and 3C 273. In most observations, the region $r < 1''$ is contaminated by artifacts left by the PSF subtraction. The saturated areas in the images of HE 1029$-$140 and 3C 273 are larger; for those two cases, the inner radii used were $1.5''$ and $2.0''$, respectively. The outer radii chosen in general represent how far we could see the host galaxy (see Table 3). The aperture magnitudes calculated using an inner radius $r = 1.0''$ are typically ~ 0.6 mag fainter than the total magnitude for the galaxy that was estimated by fitting a model (see §§ 5.2–5.3) to the measured surface brightness. A difference between aperture and model magnitudes is expected because the aperture magnitudes do not include

the area within $1''$ of the quasar; all of the models we considered have surface brightnesses that increase monotonically toward the center.

5.2. One-Dimensional Radial Profiles

The one-dimensional azimuthally-averaged surface brightness profiles of the host galaxies were constructed from the *HST* data after subtraction of a best-fit stellar PSF. Regions affected by saturation, diffraction spikes, or residual artifacts from the PSF subtraction were not included in the azimuthally averaged profiles. For each galaxy, we obtained a best-fitting exponential disk (henceforth Disk) and a de Vaucouleurs (1948, henceforth GdV) profile that fits the observed data in the region $r \geq 1''$. The total magnitudes obtained this way are systematically brighter than the ones obtained by aperture photometry (§ 5.1) which excludes the innermost, saturated regions of the profiles.

5.3. Two-Dimensional Fit

The *HST* imaging provides greater detail than has been available previously in ground-based images of luminous quasars. Traditionally, the properties of host galaxies have been determined in ground-based studies by making model fits to azimuthally-averaged radial profiles (see § 5.2).

To take advantage of the *HST* resolution, we have developed software to fit a two-dimensional model to the PSF-subtracted quasar images. For each quasar, we fit an analytic galaxy model (exponential disk or de Vaucouleurs profile) to the data and calculated the χ^2. The area used for the fit was approximately an annular region, centered on the quasar, that excluded the central area ($r < 1.0\,''$), and the remnants of the diffraction spikes or other artifacts clearly due to improper PSF subtraction. We fit four parameters:

the (x,y) pixel position of the center, the total number of counts, and the radius (effective radius or scale length) in the galaxy model.

We begin the iteration by giving the software the position of the quasar nucleus, and calculate only the total number of counts. The number of counts found in this step is entered as the initial guess for the galaxy brightness, and the program then fits the counts and radius, keeping the position fixed. Finally, we supply the software with the previously calculated counts and radius and ask the software to fit all four parameters.

We tested the software for the two-dimensional fits in different ways. Initially we created two model galaxies: a disk and an elliptical galaxy. We checked how well the two-dimensional software reproduced the position of the center of the model galaxies, the scale length or effective radius, and the total number of counts. We made extensive checks by varying the input parameters and the order in which the parameters were fit. The best results were achieved when we followed the three step iterative process in the order described above. We fit each model galaxy with an exponential disk and a de Vaucouleurs model - the smallest χ^2 residuals were obtained when the disk galaxy was fit by an exponential disk model, and the elliptical was fit by a de Vaucouleurs model. For the model galaxies, the discrepancy in position and size were < 1 pixel. The discrepancy in the total number of counts was $\sim 1\%$. The accuracy achieved in the simulations is greater than can be achieved with the real data, because of the imperfect subtraction of the PSF for the HST images.

The host galaxies of PG 0052+251 and PHL 909 were also used to test the two-dimensional software. We compared the software output position with our measured position for the center of the galaxy (agreement better than $0.2''$), compared the total number of counts with the value we estimated from aperture photometry (agreement turned out to be 0.1 mag for PG 0052+251, and 0.5 mag for PHL 909), and verified that the output scale length or effective radius were plausible.

6. MAGNITUDES AND POSITIONS OF HOST GALAXIES

In this section, we report on the measurements of the magnitude and position of the host galaxies.

In Table 3 we list the magnitudes for the host galaxies measured using aperture photometry and for a few cases the surface brightness method. The inner and outer radii used in performing aperture photometry are listed as well. The outer radius indicates how far from the quasar the host galaxy was clearly visible. We transformed the measured F606W aperture magnitudes to V applying k-corrections calculated by Fukugita et al. (1995). Given the redshift of the quasar and the morphological type of the host, we used the Fukugita et al. Table 6 and Figure 14b to obtain the $(F606W - V)$ color. For the cases in which we are uncertain about the morphological type of the host, we assumed an average of the $(F606W - V)$ color for ellipticals and Sab galaxies.

Table 4 lists the results for the one-dimensional and two-dimensional galaxy model fitting. The two-dimensional models are somewhat fainter than the corresponding one dimensional fits. Specially, we find:

$$\langle m_{\rm 606W,2-D} - m_{\rm 606W,1-D} \rangle = \begin{cases} 0.4 \pm 0.2, & \text{GdV} \\ 0.3 \pm 0.1, & \text{Disk} \end{cases} . \qquad (1)$$

The magnitudes obtained by model fits are brighter than those obtained by aperture photometry since the models include estimated contributions from the inner (saturated) regions of the images. On average

$$\langle m_{\rm 606W,1-D} - m_{\rm 606W,aperture} \rangle = \begin{cases} -1.1 \pm 0.2, & \text{GdV} \\ --0.4 \pm 0.2, & \text{Disk} \end{cases} . \qquad (2)$$

As equation (3) shows, the magnitudes of the host galaxies estimated by fitting a GdV model to the azimuthal averaged radial profile of the residual light are on average 1.0 mag brighter than the magnitudes obtained from aperture photometry; fitting an exponential

disk model gives magnitudes that are on average 0.5 brighter than the results from aperture photometry. For the two-dimensional model fits, we have on average

$$\langle \mid m_{606\mathrm{W},2-\mathrm{D}} - m_{606\mathrm{W,aperture}} \mid \rangle = \begin{cases} -0.7 \pm 0.2, & \text{GdV} \\ --0.2 \pm 0.1, & \text{Disk} \end{cases} . \tag{3}$$

Table 5 lists our best-estimate absolute V magnitudes. In computing the entries in Table 5, we used the k-correction of Fukugita et al. (1995) that are listed in the next-to-last column of Table 3. In computing the absolute magnitudes, we selected the best-fit model based on the morphology of the host galaxy, unless the morphology is uncertain, and for those cases we list the model that gives the smallest χ^2 residuals.

The results from the two-dimensional fits indicate that the host galaxies are, on average, centered on the quasar with:

$$\langle \ \Delta r \ \rangle \ = \ 0.4 \pm 0.4 \text{ kpc.} \tag{4}$$

The host galaxies are typically centered within 400 pc of the location of the quasar point source. If we eliminate from the comparison the most extreme examples of especially complex environments (0316−346, PG 1012+008, and PKS 2349−014) the results are,

$$\langle \ \Delta r \ \rangle \ = \ 0.2 \pm 0.2 \text{ kpc.} \tag{5}$$

The 2-D (1-D) GdV model gives magnitudes for the host that are on average 0.6 mag (0.7 mag) brighter than the exponential disk estimates.

7. COMPANION GALAXIES

Inspection of the *HST* images of the quasar fields reveals a number of companion galaxies projected close to the quasars. The relatively long exposures (1100 or 1400

seconds), combined with the excellent angular resolution, allowed galaxies to be identified down to limiting magnitude $m(F606W) \lesssim 25.0$ and as close as $1''$ or $2''$ from the central quasar. We performed aperture photometry on the galaxies in the quasar fields using circular apertures with radii of $0.3''$ to $10''$, as appropriate.

We counted the number of companion galaxies brighter than a specified limiting absolute magnitude that were found to have a metric separation from one of the quasars of less than or equal to some predetermined distance. We choose *a priori* a limiting absolute magnitude of $M_V = -16.5$ (four magnitudes fainter than L^*) and a maximum separation of 25 kpc (see Paper II).

Table 6 lists all galaxies found around the quasars that satisfy these specifications. This table gives for each quasar the number of companion galaxies that are at least as bright as $M_V = --16.5$ (if they have the same redshift as the quasar) and that are projected within 25 kpc of the center of light of the quasar. The separations both in arcseconds and in kpc are also given in Table 6, along with the brightnesses of the companion galaxies, tabulated in both apparent and absolute magnitude.

The density of companion galaxies brighter than $M_V = -16.5$, within 25 kpc of the quasars, may be higher around quasars with elliptical hosts. There are 2 companions for 4 spiral hosts and 13 companions for 12 elliptical hosts.

Fisher et al. (1996) examined the clustering of galaxies around all the quasars in this sample and found a significant enhancement of galaxies within a projected separation of $\lesssim 100\ h^{-1}$kpc of the quasars. Modeling the quasar/galaxy correlation function as a power law with a slope given by the galaxy/galaxy correlation function, Fisher et al. find that the ratio of the quasar/galaxy to galaxy/galaxy correlation functions is 3.8 ± 0.8. The galaxy counts within $r < 15\ h^{-1}$kpc of the quasars are too high for the density profile to have an appreciable core radius ($\gtrsim 100\ h^{-1}$kpc). These results provide further support for the

idea that low redshift quasars are located preferentially in groups of 10–20 galaxies rather than in rich clusters. Fisher et al. do not detect a significant difference in the clustering amplitudes derived from radio loud and radio quiet subsamples.

8. COMPARISON WITH GROUND-BASED OBSERVATIONS

In this section we compare the results of *HST*-based images of luminous quasars with previously-published representative analyses of ground-based observations. In § 8.1, we compare our *HST* measurements with Véron-Cetty & Woltjer (1990) i-band results, in § 8.2, with Dunlop et al. near-infrared images, and in § 8.3, with McLeod & Rieke (1994b) H-band observations.

8.1. Véron-Cetty & Woltjer: Annular Regions

Véron-Cetty & Woltjer (1990) suggested that the apparent magnitudes of host galaxies should be measured in a fixed metric annulus that is well removed from the quasar nucleus. They proposed an annular region of 12.5 kpc to 25.0 kpc for $\Omega_0 = 0.0$ and $H_0 = 50$ km $s^{-1}Mpc^{-1}$. The Véron-Cetty & Woltjer proposal compares directly measurements of the same quantity made by separate groups using different techniques. In this way, measurement uncertainties can be separated from differences caused by the variety of choices in the models used to fit to the observations.

We have three objects in common with Véron-Cetty & Woltjer: PKS 1302−102, PKS 2135−147, and PKS 2349−014. The specified annular regions are 2.17″ and 4.35″, 2.82″ and 5.63″, and 3.15″ and 6.30″ for the three quasars, respectively. All three quasars have close companion galaxies in the regions specified by Véron-Cetty & Woltjer (see Table 6). The close companions of PKS 1302−102 and PKS 2349−014 were not noticed on

the ground-based images.

Table 7 summarizes the aperture photometry that was performed in the same annular regions as Véron-Cetty & Woltjer. We list the i-band annular magnitudes obtained by Véron-Cetty & Woltjer and their estimated absolute V-magnitude, converted to the cosmological parameters used in this paper, the absolute magnitude we measured in the *HST* images (excluding the light of the companions) with the F606W, and our estimated absolute V-magnitude. We also include in the table the total absolute V-magnitude Véron-Cetty & Woltjer obtained for the host galaxies (fitting a spheroidal model) and our estimated 2-D model $V-$band host galaxy magnitude.

The agreement between our results and the ground-based observations of Véron-Cetty & Woltjer for the aperture photometry between 12.5 kpc and 25 kpc is satisfactory, but not as precise as we would have hoped. The average difference between our estimated M_V and that of Véron-Cetty & Woltjer is

$$\langle M_{V(i)} - M_{V(F606)} \rangle_{(12.5-25\mathrm{kpc})VCW} \ = \ -0.4 \pm 0.1 \text{ mag.} \tag{6}$$

This discrepancy cannot be attributed to the contribution of companion galaxies. In the case of PKS 1302−102, the companion at $2''$ lies inside the annular region studied (12 kpc to 25 kpc); if we include its light, our estimated brightness for the host increases 0.2 mag. Part of the companion galaxy $5.5''$ from PKS 2135−147 lies in the annular region considered, but Véron-Cetty & Woltjer (1990) also subtracted its contribution from their measurements. The compact companion at $2''$ of PKS 2349−014 lies outside the annular region considered.

The Véron-Cetty & Woltjer magnitudes for the host that were estimated by fitting a spheroidal model are typically about one mag brighter than our 2-D model magnitudes, i.e.,

$$\langle M_{V(i)}(\text{model})_{VCW} - M_{V(F606)}(2-\text{D})\rangle = -0.8 \pm 0.4 \text{ mag} . \tag{7}$$

Table 8 lists the annulus measurements of the whole sample. For the range of redshifts in our sample, the designated Véron-Cetty & Woltjer annular region 12.5 kpc to 25 kpc ($H_0 = 50$ km s^{-1}Mpc^{-1}, $\Omega_0 = 0.0$) corresponds approximately to 6 kpc to 12 kpc with our chosen cosmological parameters. In Table 8 we list for each quasar the inner and outer radii in arcsec, the apparent and absolute $F606$ aperture magnitude, and the absolute V magnitude in the annulus (see adopted values for $F606 - V$ values in Table 3). As stressed by Véron-Cetty and Woltjer (1990), these annular measurements can be compared to future measurements obtained by other techniques.

8.2. Dunlop et al.

Dunlop et al. (1993) obtained deep ground-based near-infrared images in the K band for a sample of nearby ($z < 0.4$) radio loud and radio quiet quasars. They built a library of infrared PSFs by observing many bright stars. The nuclear component was removed by selecting from the library the PSF that produced the best match to the quasar PSF. The stellar PSF was scaled to the same height as the central peak of the quasar. Dunlop et al. suggest that their procedure will cause the luminosities of the hosts to be overestimated, but in practice the sign of the error could depend on whether there was a positive or a negative fluctuation in the measured light in the central peak. An aperture diameter of $12''$ was used by Dunlop et al. to measure the magnitudes of the hosts. We have eight quasars in common.

Table 9 compares the HST and the Dunlop et al. results. We list the K magnitude they obtained for the host galaxies using an aperture of diameter $12''$, the K absolute

magnitude for the host, using our comoslogical parameters, the color $(V - K)$ for an elliptical galaxy obtained from Bruzual & Charlot (1993), the corresponding V absolute magnitude expected, the 2-D model V absolute magnitude estimated from the HST-F606W images (see next-to-last column of Table 5), and the difference between the V absolute magnitude derived from both bands, ΔM_V. The average discrepancy is

$$\langle \mid \Delta M_V \mid \rangle \; = \; \langle \mid M_{V(K)} - -M_{V(F606)} \mid \rangle \; = \; 1.0 \pm 0.6 \text{ mag.} \qquad (8)$$

For seven of the eight cases, our estimated magnitudes are brighter than obtained by Dunlop et al. (1993).

8.3. McLeod & Rieke

McLeod & Rieke (1994a,b) obtained ground-based images of luminous quasars in the H-band. For most cases, they determined a one-dimensional profile for the quasar, subtracted a stellar PSF, and then fit the resulting profile with an analytic galaxy model. We have fourteen quasars in common. To compare the results, we transform both the H-band and the F606W magnitudes to the V band. We used the k-corrections and the relative sensitivities of the different bands calculated by Fukugita et al. (1995) to convert our F606W measurements to V (see § 6).

To transform the H-band magnitudes to V, we assumed $(V - H) \sim 3.0$ for normal galaxies plus a k-correction given by McLeod and Rieke (1995). For objects not in their table, we interpolated in redshift to obtain the expected $(V - H)$ for a normal galaxy.

Table 10 lists the following information: column 1: quasar; column 2: McLeod-Rieke H-band magnitude for the host galaxy; column 3: color $(V - H)$ for normal galaxies including k-correction; column 4: absolute V-magnitude based on the H-band measurements

and calculated assuming $H_0 = 100$ km s^{-1}Mpc^{-1}, and Ω_0; column 5: absolute 2-D model V-magnitude estimated from F606W images; and column 6: difference between absolute V-magnitude estimated from H-band and F606W images. The average discrepancy is

$$\langle \mid M_{V(H)} - M_{V(F606)} \mid \rangle = 0.4 \pm 0.2 \text{ mag.} \tag{9}$$

For 8 of the 14 cases, the McLeod & Rieke luminosities are brighter than the *HST* luminosities. In some cases, the difference is clearly due to the McLeod & Rieke magnitudes also including the companion galaxies (see PG 1012+008 in Figures 1 and 2, and the discussion in § 9).

9. COMMENTS ON INDIVIDUAL CASES

In this section we will discuss the images of each of the quasars. Table 2 summarizes the morphological information obtained from the *HST* images and Tables 3-5 give the inferred luminosities of the host galaxies. For comparisons, the absolute magnitudes reported by other authors have been converted to our cosmological parameters. Information about close galaxy companions is summarized in Table 6.

Measurements of the surface brightness along the major axes of the relatively bright elliptical host galaxies of PHL 909, PG 0923+201, PKS 1004+130, HE 1029−140, PG 1116+215, 3C 273, and PKS 2135−147, do not show evidence of discontinuity in the light distribution. Thus all the apparently elliptical hosts discussed below for which we could make detailed photometry satisfy the criterion of having smooth light distributions. The *HST* images reveal spiral host galaxies with H II regions for three quasars, PG 0052+251, PG 1309+355, and PG 1402+261. It should be feasible to obtain spectra of the brightest H II regions. The spectra may reveal the composition of the material which makes up the

quasar hosts and perhaps provide further clues to the quasar phenomenon.

PG 0052+251: The host is a beautiful spiral galaxy (see Bahcall et al 1996 for a detailed discussion). The spiral host is evident even in our 200 s exposure. The southern spiral arm extends the furtherest from the quasar (in the direction of the companion). There is good agreement between the absolute V magnitude estimated from the McLeod and Rieke (1994b) H-band image measurements and our 2-D model estimate based on the *HST* images. Miller (1996, private communication) has recently obtained spectra for some of the bright H II regions identified (Bahcall et al. 1996) in the *HST* images. The H II regions observed have the same redshift as the quasar. The second and third quasar nuclei suggested by Hutchings, Janson & Neff (1989; the second nucleus was confirmed by Dunlop et al. 1993), are seen on the *HST* images to be, respectively, a bright H II region in the spiral arm of the host galaxy, and a foreground star in the Galaxy.

PHL 909 (0054+144): The quasar host is a normal elliptical E4 galaxy (see Bahcall et al 1996 for a more extensive discussion and a variety of images). This radio quiet quasar does not occur in a spiral galaxy, as the conventional view had suggested before the *HST* observations. We did not detect extended emission towards the western companion galaxy, as suggested by Dunlop et al (1993). The elliptical host is apparent in our 200 s image.

NAB 0205+02: The appearance of this quasar in the *HST* images (see Fig. 1) resembles, on visual inspection, that of a bright star. Indeed, it is hard to distinguish the quasar from a star by just looking at the images (see Figure 1). After PSF subtraction, we detect a small disk-like host galaxy (see Figure 2), with size and inclination similar to the companion $8.3''$, position angle PA $= 332^{\circ}$. The scale length of the host is only ~ 1.2 kpc and the absolute visual magnitude is -19.1.

Figure 3 compares the host image after subtraction of a blue standard star, MMJ 6481 (see Figure 3a), and after the subtraction of a red standard star, F141 (see Figure 3b). The

image of the host galaxy obtained after the subtraction of the PSF for the blue standard star is significantly clearer than the image obtained using the red-star PSF. However, there is very little difference quantitatively, < 0.1 mag, between the host galaxy magnitudes we determined from the two subtracted images.

Stockton, Ridgway, & Kellogg (1996 in preparation) recently obtained ground-based images in two line-free continuum bands that show a definite host galaxy elongated roughly NW-SE as well as some extended low-surface-brightness material to the west. In agreement with our results, they report that the host galaxy has about the same luminosity and orientation as the companion in the shorter wavelength image, but the host has somewhat redder colors than the companion. NAB 0205+02 was not resolved in the deep images taken by Smith et al (1986).

Figure 4 shows a fascinating object, first noticed by Stockton and MacKenty (1987). The object, which is $12''$ to the East of the quasar, is visible in their [O III] image, but absent from their continuum image. It appears as a point-source with a bright jet-like structure to the south and a much fainter and curved extension to the north. The width of the jet and of the curved extension is less than 0.3 kpc. The total apparent F606W magnitude of the object is 22.6, and the extension of the jet-like structure and curved tail are $0.7''$ (1.2 kpc) and $1.1''$ (1.9 kpc), respectively. The offset of this object from the quasar position is $\Delta\alpha = 12.1\,''$ and $\Delta\delta = 1.7\,''$.

0316−346: The morphology of the host environment is complex, probably the result of gravitational interactions with a neighboring galaxy. Figures 1 and 2 show clearly what appear to be tidal tails that extend about 20 kpc west of the quasar. There are also bright diffuse clumps within ~ 5 kpc of the quasar, which may contain H II regions. We do not see unambiguous signs of a compact remnant close to the center of light of the quasar. The radial profile is reasonably described by an exponential disk from radius $\sim 1''$ to $6''$. There

is a relatively bright peculiar spiral galaxy ($m_{606} = 20.7$ mag) projected $26.7''$ of the quasar, PA = 67°.

PG 0923+201: The host of this radio quiet quasar is an E2 elliptical, a member of a small group of galaxies. The two galaxies at $11.0''$, PA = 151°, and $15.1''$, PA = 162°, have redshifts similar to the quasar (Heckman et al 1984); the companion at $15''$ SE is not shown in Figures 1 and 2. The V magnitude estimated from McLeod & Rieke (1994b) H-band images is in good agreement (0.1 mag) with the magnitude determined from our 2-D model.

PG 0953+414: Low surface brightness fuzz was detected in the early *HST* images (Bahcall et al. 1994, 1995a) and confirmed to be real by longer (Cycle 5) exposures. We are unable to establish the morphology of the fuzz, which is faint and extended. Hutchings et al (1989) suggested, on the basis of ground-based images, that the host of the quasar has spiral structure and is possibly interacting. The HST images do not provide convincing evidence for or against this conjecture. Spectroscopy of the fuzz around the quasar obtained by Boroson et al (1985), shows that the off-nuclear spectrum is dominated by a red continuum with $H\alpha$ and possibly [S II] emission; Mg Ib absorption might also be present. The absolute V magnitude derived from McLeod and Rieke (1994b) H-band observations is 0.5 mag brighter than our 2-D model estimate.

PKS 1004+130: The host is a bright elliptical, about as bright as the brightest cluster galaxies. There seems to be some structure in the inner region of the host ($r < 2.5''$). The absolute V magnitude derived from McLeod and Rieke (1994b) H-band observations is 0.8 mag fainter than our 2-D model estimate. Stockton and MacKenty (1987) presented narrow band [O III] images of this quasar, but did not find any significant extended luminosity in the region between ~ 7 to 28 kpc (for $q_0 = 0.5$ and $H_0 = 100$ km s^{-1}Mpc^{-1}). Stockton (1978) obtained spectroscopic observations of the galaxies around the quasar and found that two of them have redshifts similar to the quasar redshift. One of the galaxies is

separated by 33.4″ (79.8 kpc, PA = 233°; not shown in Figures 1 and 2) from the quasar and has $m_{606} = 20.0$ mag; the other is not in our *HST* image field of view.

PG 1012+008: This quasar is "caught in the act" of merging. The host of this quasar is seen in Figures 1 and 2 to be merging with a bright galaxy. The distance between the two galactic nuclei is 6.7 kpc (3.3″). There is another compact galaxy 6.8″ (12.4 kpc) North of the quasar, probably taking part in the interaction as well. Both interacting companions are also visible in our 200 s exposure.

Figure 5 shows an expanded view of the PG 1012+008 image. Heckman et al. (1984) obtained spectra for both galaxies and found the expected absorption lines ($H\beta$, Mg I, Fe II and Na I) at the same redshift as the quasar. The absolute V magnitude based on the H-band measurement by McLeod & Rieke (1994b) is 0.9 mag brighter than our 2-D model estimated value; we believe that part of this discrepancy is caused by the light of the merging galaxy being included in their model fit.

HE 1029−140: This radio quiet quasar has a bright elliptical host galaxy. Some faint structures resembling shells are seen at $\sim$ 11″ and 19″ from the quasar. There is a compact galaxy 4.1″ North from the quasar; spectroscopy is required to determine if it is associated with the quasar. Wisotzki et al. (1991) obtained R-band images and, based on spheroidal model fits, reported the host to be a giant elliptical with $R = 15.2$ mag and $M_R = -22.0$ mag. Assuming $(V - R) \sim 0.8$ for elliptical galaxies at $z \sim 0.1$ (Fukugita et al. 1995), their absolute V magnitude for the host is −21.2 mag. We obtained $M_V = -20.8$ by fitting a GdV model to the azimuthally averaged profile of the host.

Wisotzki (1994) measured redshifts of galaxies in the field of HE 1029−140 and found that four galaxies have redshifts similar to the quasar. Wisotzki did not detect the close compact object at 4″ projected separation.

The closest galaxy with a redshift known to be similar to the quasar lies at 134 kpc (=109.4″) PA = 26° and was detected in WF2 (not shown in Figures 1 and 2). The *HST* images show that this Wisotzki companion galaxy has $M_V \sim -19.1$ ($m_{606} = 17.7$) and is highly disturbed, probably an advanced stage of merger between two disk galaxies. Two possibly galactic nuclei, separated by 1.4″, are visible, as well as H II regions.

There is a $m_{606} = 17.9$ mag galaxy projected at 22.9″, PA = 23°, of the quasar, which Wisotzki showed is a background galaxy with $z = 0.162$. Wisotzki classified this galaxy as an elliptical, but the *HST* images show that it is a spiral galaxy (type ∼Sab).

PG 1116+215: The host of this radio quiet quasar is probably an elliptical galaxy. The bright central region is surrounded by a faint smooth fuzz. Some arc-like structures are seen in the center, but are almost certainly PSF artifacts. The one-dimensional profile is reasonably described by a de Vaucouleurs model. The V magnitude estimated from McLeod & Rieke (1994b) H-band images is in good agreement with the magnitude determined from our 2-D model.

McLeod and Rieke (1995) applied the techniques they developed to study their H-band ground-based images, to reanalyse the *HST* Archive images of PG 1116+215. They subtracted just enough of the PSF of the red standard star, F141 ($B - V = 1.11$), from the azimuthally-averaged quasar 1-D profile to make the residual profile almost turn over in the center. Because the *HST* images were saturated in the center, McLeod & Rieke normalized the light profile just outside the saturation region. We note, however, that the region inside $r \sim 2''$ is heavily contaminated by PSF artifacts when the PSF of the red star F141 is used for the subtraction. If F141 is used for the PSF subtraction, there are artifical radial spikes - which are not visible in their published *HST* image of this quasar. McLeod and Rieke state that the host of PG 1116+215 “looks nearly identical” to a field galaxy detected in WF4. An *HST* image of this field galaxy was published in Bahcall et al. (1995a, Figure

5c). The field galaxy is rich in morphological details: it is a barred spiral with internal and external rings (RSBb). If it is at the same distance as the quasar, its absolute V magnitude is -20.9. Although the host and the field galaxy have apparently similar luminosities, they are morphologically quite different.

PG 1202+281: The host of this radio quiet quasar, also known as GQ COM, is a small elliptical E1 galaxy. Stockton and MacKenty (1987) showed that the compact galaxy $\sim 5''$ from the quasar, PA $= 71°$, is at the same redshift as the quasar. Boroson et al. (1985) reported that the off-nuclear spectra are dominated by a red continuum, with [O III] lines and possibly $H\alpha$ in emission, and a possible Mg Ib absorption feature. The V magnitude estimated from the McLeod & Rieke (1994b) H-band images is in good agreement with the magnitude determined by our 2-D model.

3C 273 (PG 1226+023): The host galaxy is an elliptical. The V magnitude estimated from the McLeod & Rieke (1994b) H-band images is in good agreement with the magnitude determined by our 2-D model. Using deep ground-based CCD images, Tyson et al. (1982) obtained $M_V \sim -22.5$ for the host, which is in good agreement with our best 2-D model magnitude of $M_V = -22.1$. The host is somewhat brighter than the brightest galaxy in a rich cluster. Stockton (1980) measured redshifts for galaxies in the 3C 273 field and found that four of them have redshifts similar to the quasar, in agreement with the suggestion of Bahcall & Bahcall (1970). One of those galaxies was detected (a spiral galaxy) in WF4: it lies at $75''$ East of the quasar ($\sim$ 133 kpc) and its redshift is $z = 0.1577$. Wyckoff et al. (1981) obtained $R = 16.3$ for the host, which is equivalent to $M_V \sim -21.3$ mag. The inner part of the jet is barely visible in the PSF subtracted image in Figure 2. *HST* and Merlin observations of the 3C 273 jet are reported in Bahcall et al. (1995).

PKS 1302−102: The *HST* images show there are two small compact galaxies at $1''$ and $2''$ from the quasar, which are expected to spiral into the quasar in a time short compared

to the Hubble time (Bahcall et al. 1995a). The presence of these very close companions can be seen most clearly in the expanded image, Figure 8, of Bahcall et al. (1995a). Hutchings and Neff (1992) performed optical imaging with $0.5''$ resolution and reported structures at the positions of those galaxies; they suggest the host is a mildly disturbed elliptical galaxy. The PSF-subtracted residual image (see Figure 2) appears to the eye to be similar to an elliptical galaxy, but an exponential disk fits the data slightly better. The absolute V magnitude estimate for the host galaxy is 0.4 mag fainter than the value determined from the McLeod & Rieke (1994b) H-band observations, and is 0.9 mag fainter than the value estimated from i-band images (Véron-Cetty & Woltjer 1990). Wyckoff et al. (1981) obtained $R = 19.0$ for the host; using the Fukugita et al. (1995) transformations of galaxy colors, this corresponds to $M_V \sim -20.0$.

PG 1307+085: The host appears to be a small early-type galaxy. The absolute V magnitude estimated from our 2-D model of the HST image is 0.2 mag fainter than the value derived from the McLeod & Rieke H-band images.

PG 1309+355: Figure 6 shows an expanded view of the image for PG 1309+355 with lower contrast than shown in Figures 1 and 2. The details near the center of PG 1309+355 are shown more clearly in Figure 6, after a best-fit stellar PSF has been subtracted. This quasar has a bright early-type host galaxy, probably an Sab. Tightly wrapped spiral arms are clearly seen in the inner region surrounding the center of the quasar. Overall, the GdV model describes the radial profile better than the exponential disk model. The absolute V magnitude estimated from our 2-D model of the HST image is 0.1 mag brighter than the value derived from the McLeod & Rieke (1994b) H-band images.

PG 1402+261: Figure 7 shows an expanded view of the image of this quasar at two different contrast levels. The HST images show that the host is a beautiful spiral. After the PSF subtraction a bar and a possible inner ring are visible. The morphological type is

approximately SBb(r?). H II regions are also visible along one of the spiral arms; they are less prominent than the H II regions seen in the spiral host of PG 0052+251. The relative positions and magnitudes of the brightest H II regions are marked for identification in the upper panel in Figure 7. Table 11 lists for each H II region the aperture magnitude, the distance to the quasar nucleus, and the offset in right ascension and declination between the H II region and the quasar nucleus. The magnitudes were measured using apertures of $0.3''$.

PG 1402+261 is a relatively isolated quasar. Stockton and MacKenty (1987) did not find any significant extended [O III] emission around the quasar. McLeod and Rieke (1994b) obtained H-band images; the absolute V magnitude based on their measurement is 0.5 mag brighter than the value estimated with our 2-D model of the *HST* images.

PG 1444+407: The host galaxy of this quasar is smooth and is elongated in the NS direction. After the PSF subtraction, the nuclear region is seen as an extended structure running NE-SW, as shown in Figure 2. A bar may be present. The exponential disk model describes the radial light distribution a little better than does the GdV model. The overall appearance is most similar to an E2 galaxy. Hutchings and Neff (1992) originally suggested the possibility of a bar in this host, which they proposed might be in an advanced stage of the merger of galaxies of very different masses. The absolute V magnitude estimated from our 2-D model of the *HST* image is 0.5 mag fainter than the value derived from the McLeod & Rieke H-band images.

3C 323.1 (PG 1545+210): A low surface-brightness elliptical host galaxy appears in the *HST* images, as well a neighboring companion at a projected distance of ~ 7 kpc, ($2.7''$, PA = $292°$), (see Figures 1 and 2). The V magnitude of the host galaxy determined from the H-band images by McLeod and Rieke (1994b) is 0.4 mag brighter than the value derived from our 2-D model of the *HST* images. More recently Neugebauer et al. (1995) obtained H and K-band images of 3C 323.1; their estimated model fit H-band magnitude

for the host agrees with McLeod & Rieke (1994b) results. Neugebauer et al. measurements suggest that if the host galaxy is a normal elliptical, its expected apparent V magnitude is ~ 17.5, and if it is an spiral galaxy, $V \sim 16.9$. These values are brighter than the V-band apparent magnitudes expected using a color transformation without reddening of our HST images (see Table 4), but are consistent with the host galaxy being a reddened elliptical, as pointed out by Neugebauer et al. (1995). The GdV one-dimensional model fits better the surface brightness radial profile of the quasar host in our HST image than does the exponential disk model.

Stockton (1982) took spectra of the companion galaxy at $2.7''$ from the quasar, and apparently detected [O III] at the same redshift as the quasar. Complex, asymmetric extended [O III] emission is seen surrounding the quasar in [O III] images obtained later by Stockton and MacKenty (1987). However, there is no excess of emission at the companion galaxy position in the [O III] images. Stockton and MacKenty conclude that the previously reported detection of [O III] emission in the spectrum of the companion galaxy was fortuitous, since the emission is due to the general distribution of ionized gas surrounding the quasar. Neugebauer et al. found that the H and K model fit magnitudes obtained for the companion galaxy, when combined with the HST measurements by Bahcall et al. (1995a), gives a color $V - H$ consistent with the companion galaxy being a faint elliptical at the redshift of the quasar.

PKS 2135−147: The quasar host is an elliptical galaxy; the envelope is not featureless like PHL 909, but contains some faint clumps. The image suggests the presence of a jet at PA $\sim 26°$, with visual extension of $\sim 2.4''$ and width $\sim 0.5''$. The surface brightness of the jet-like feature is 23.4 mag arcsec^{-2} (F606W), at $1.7''$ from the quasar center of light. Many galaxies are seen in the field; the closest companions to the quasar are at $1.9''$, PA = 128°, and $5.5''$, PA = 119°, seen in Figures 1 and 2. Stockton (1978, 1982) obtained spectra of

the field galaxies and found that four are at the same distance as the quasar, including the closest companions at projected separations of 1.9″ and 5.5″. Somewhat later, Stockton & MacKenty (1987) obtained [O III] images. They noted that the companion 2″ southeast did not appear enhanced in the [O III] images, indicating that the emission lines seen in the combined spectrum are due to extended emission around the quasar that is not confined to the companion. Hickson and Hutchings (1987) reported Mgb in the spectrum of the secondary nucleus (the galaxy at 2″ SE) corresponding to a galaxy at the redshift of the quasar.

PKS 2135−147 has been included in many imaging programs. For example, Dunlop et al. (1993) measured $M_K(\mathrm{host}) = -24.2$, which gives $M_V \sim --21.0$. Our 2-D model analysis of *HST* images gives $M_V \sim -21.1$. Véron-Cetty & Woltjer (1990) obtained i-band images and measured aperture photometry in an annulus with radii 12.5 kpc and 25 kpc. They estimated $M_V = -19.9$. We measured the absolute magnitude of the host in our *HST* images within the same annulus and obtained $M_V \sim --19.4$. Smith et al. (1986) measured the absolute blue magnitude to be $M_B \sim -21.5$, which converts to $M_V \sim -19.9$ (if $(B-V) \sim 1.6$ for an elliptical galaxy at $z = 0.2$). Wyckoff et al. (1981) obtained $R = 17.8$, which corresponds to $M_V \sim -19.3$.

PKS 2349−014: The quasar host galaxy is undergoing gravitational interaction, which is evidenced by apparently tidal arms and possibly also by a huge ($\sim$ 50 kpc) diffuse off-center nebulosity. A compact companion galaxy at 2″ E is detected in the *HST* images. Bahcall et al. (1995b, 1995c) provide an extensive discussion of this object and include a number of different images (the tidal wisps and extended nebulosity are seen most clearly in their Figures 1 and 2; the close companion galaxy is featured in their Figure 3). Dunlop et al. (1993) suggests that the quasar is interacting with the three closest galaxies SE of the quasar. The *HST* images do not show evidence for this interaction; the three galaxies do

not seem to be morphologically disturbed and no obvious link between them and the quasar is seen. Dunlop et al. measured $M_K(host) = -24.7$, which gives $M_V \sim - - 21.5$. Our 2-D model fits to the *HST* image of the host gives $M_V \sim -22.0$, similar to the light from a brightest cluster galaxy.

The radial profile of the interacting system PKS 2349−014 is well described by a de Vaucouleurs model. As pointed out by Toomre (1995) and Bahcall et al. (1995b), there are some morphological resemblances between PKS 2349−014 and NGC 3921. Schweizer (1996) has carefully and extensively studied NGC 3921, suggesting that it is the result of a merger between two disk galaxies and is now a protoelliptical. In this case also the mean light distribution of the system is well described by a $r^{1/4}$ law.

10. SUMMARY AND DISCUSSION

The images shown in Figures 1 and 2 establish the two main conclusions of this paper: 1) The most luminous nearby quasars exist in a variety of environments; 2) *HST* observations provide unique information about the circumstances of the quasar phenomenon. Many of the most important results obtained in this paper are visible on the unprocessed images shown in Figure 1, which can be compared with the images with a stellar PSF subtracted shown in Figure 2. The subtraction of a stellar PSF is important in about half of the cases.

Our results are based upon a representative sample of 20 of the most luminous known ($M_V < -22.9$) and nearby ($z < 0.30$) quasars. The characteristics of the sample are summarized in Table 1 and Section 2.1.

In separate subsections, we summarize and discuss below our results on host morphologies, host luminosities, comparisons with our earliest analyses, close companions,

ground-based studies, and future work.

10.1. Host Morphologies

Figures 1 and 2 show three hosts that apparently are normal spirals with H II regions (PG 0052+251, PG 1309+355, and PG 1402+261), seven ellipticals (PHL 909, PG 0923+201, PKS 1004+130, HE 1029−140, PG 1116+215, 3C 273, and PKS 2135−147), as well as three obvious cases of current gravitational interaction (0316−346, PG 1012+008, and PKS 2349−014). There are also five other hosts that appear to be elliptical galaxies and are listed as En(?) in Table 2. The hosts for two of the quasars (NAB 0205+02 and PG 0953+414) are faint and difficult to classify.

The host galaxies are centered on the quasars to the accuracy of our measurements, ± 0.4 kpc (see Section 6 and Equation 6).

Seven of the 14 radio quiet quasars in our sample occur in hosts that are classified as elliptical galaxies in Table 2. Two particularly beautiful examples of elliptical hosts for radio quiet quasars are shown in Figures 1 and 2 for PHL 909 and HE 1029−140. We have presented a more extensive discussion of the host of PHL 909 in Bahcall et al. (1996). Five of the six radio loud quasars in our sample appear to lie in elliptical galaxies. The sixth radio loud quasar, PKS 2349−014, is in a complex interacting system containing a close companion, apparent tidal tails, and a large off-center nebulosity.

The fact that about half of the radio quiet quasars in our sample have elliptical hosts contradicts the conventional wisdom that radio quiet quasars occur in spiral galaxies. However, we confirm the expectation that most radio loud quasars are in elliptical galaxies.

Three of the quasars in our sample, 0316−346, PG 1012+008, and PKS 2349−014, have been "caught in the act", i. e., the *HST* images of these quasars show dramatic

evidence of currently intense gravitational interactions. Two of the three quasars caught in the act are radio quiet. In all three cases, the unprocessed images (see Figure 1) are sufficient to reveal extended curved features that look like the tidal arms generated in numerical simulations of interacting galaxies. For 0316−346 and PKS 2349−014, there is no clear evidence for a normal host galaxy centered on the quasar. PG 1012+008 appears to be an example of a merger currently going on between two comparable galaxies. For a more extensive analysis of PKS 2349−014, the reader is referred to Bahcall et al. (1995b,c), in which the close companion, the tidal arms, the very extended off-center nebulosity, and the possible host galaxy are all discussed in some detail.

The HST images provide the best available data base to search for optical jets in nearby luminous quasars. Information on the existence or non-existence of small scale optical jets can constrain theories of the origin of radio and optical jets. We examined carefully the images of all 20 of the quasars for the existence of optical jets. With the exception of the well-known jet in 3C 273, the only other quasar for which we have found evidence for linear features is PKS 2135−147. Sensitive radio searches should be undertaken to test whether PKS 2135−147 has a radio jet. For the other quasars, we can rule out the existence of a narrow optical feature with a surface brightness in excess of 24.5 mag sec^{-2} extending more than 3 kpc beyond an inner region beginning at about 6 kpc.

10.2. Host Luminosities

We list in Table 12 our best estimates for the magnitudes of the host galaxies in our sample; these magnitudes were obtained (see § 5.3) by fitting a two-dimensional analytic galaxy model to the data. We also list the effective radius or exponential scale length, and give the morphology of the host based on visual inspection of the images (see Table 2 and § 3). The different measurements of the brightnesses of the host environments are

summarized and compared in Tables 3 and 4 and in Section 6. The average best-fit 2-D model magnitudes for the hosts of the 14 radio quiet quasars is

$$\langle M_V \rangle_{\rm model,radio\ quiet} = -20.6 \pm 0.6 \text{ mag.} \tag{10}$$

The hosts of the 6 radio loud quasars are slightly brighter,

$$\langle M_V \rangle_{\rm model,radio\ loud} = -21.6 \pm 0.6 \text{ mag.} \tag{11}$$

The fact that in our sample the radio loud quasars are, on the average, about a magnitude brighter than the radio quiet quasars cannot be explained by a selection effect resulting from the fact that the radio loud quasars have a slightly larger average redshift. In fact, the 3 radio loud quasars with $z \leq 0.20$ have $\langle M_V \rangle = --21.8$ mag and the 3 radio loud quasars with $0.20 < z < 0.30$ have $\langle M_V \rangle = -21.4$ mag.

Figure 8 shows the 2-D model absolute visual magnitudes (from Table 12) of the host galaxies (and other nebular material) versus the absolute visual magnitudes of the quasars. For two of the quasars, PHL 909 and 3C 323.1, the symbols overlap at $M_V(\text{host}) = -21.2$ and $M_V(\text{QSO}) = -22.9$.

In order to be detectable, the host must have a luminosity that is not too small when compared with the luminosity of the quasar. The minimum detectable host brightness depends strongly upon the assumed morphology of the host galaxy. We have shown by a series of numerical experiments, described in Table 3 of Paper II, that host galaxies are, on the average, visible on our images down to about 4.2 mag fainter than the quasar luminosity.

Galaxies that are smooth ellipticals are the most difficult to detect (see rows 5d and 5e of Table 3 of Paper II). For the eight quasars discussed in Paper II, smooth elliptical hosts

are, on average, visible on our images down to 3.5 ± 0.5 mag fainter than the quasar. The limiting brightnesses were determined by visually inspecting simulated galaxies placed in the actual HST quasar observations and are therefore somewhat subjective.

The diagonal line in Figure 8 represents the detection limit for smooth ellipticals in an idealized sample in which the limiting host magnitude is determined entirely by the quasar luminosity. In calculating the limiting absolute visual magnitudes for the hosts, we have included an average k-correction (see Fukugita et al. 1995) for elipticals at $z = 0.2$, as well as the average magnitude difference, 3.1 mag, between the quasar and the faintest detectable host. Thus

$$M_{\text{limiting host}} = M_{\text{QSO}} + \Delta. \tag{12}$$

The form of Equation (12) reflects the fact that the limiting host luminosity must increase linearly with the luminosity of the quasar, since by assumption the noise introduced by the quasar signal determines how faint a host can be detected. Smooth ellipticals fainter than ± 0.5 mag of the diagonal line in Figure 8 would not have been expected to be detected if this idealization of the problem is correct. For the three intrinsically faintest quasars in our sample, the noise introduced by the quasar, the host galaxy, and the background light are all similar. In practice, for our sample one might expect some flattening of the detection limit at the lowest quasar luminosities if photon noise is more important than systematic uncertainties in the subtraction of the quasar light.

McLeod and Rieke (1995) have suggested that there is a linear relation between the quasar absolute magnitude and the minimum host galaxy absolute magnitude. They interpret this linear relation, shown in their Figure 2, as indicating that a more luminous host galaxy is required to fuel a more luminous quasar. The linear relation that they find between $M(\text{host})$ and $M(\text{QSO})$ is essentially identical to our minimum detection limit

for smooth ellipticals that is shown in Figure 8 (for $V - H = 3.0$). As pointed out by McLeod(1996), the relation described by McLeod and Rieke cannot be an artifcat produced by detection limits if all of their detections are real detections. An artifical correlation would be introduced only if true non-detections were interpreted as marginal detections.

There is not convincing evidence in Figure 8 for a significant dependence of host luminosity upon the luminosity of the quasar. The apparent correlation that is suggested to the eye is due in large part to the fact that the single most luminous quasar in our sample, 3C 273, has the most luminous host.

There is a hint in Figure 8 that the average luminosity of elliptical hosts is somewhat higher than for spiral hosts. Most of this difference, however, is due to the fact that, even for the same objects (cf. Table 4), the de Vaucouleurs fitting formula yields estimated luminosities that are 0.6 mag brighter than the disk fitting function. The de Vaucouleurs formula introduces a luminosity peak in the unmeasured region that is not present in the disk formula.

Our results are inconsistent with the hosts having a Schechter luminosity function. The average absolute magnitude for a field galaxy is about 1.8 mag fainter than $M_V(L^*) = -20.5$, (for an assumed minimum luminosity of $M_V(L^*) = -17$; see, e. g., Efstathiou, Ellis, and Peterson 1988 for a discussion of the field galaxy luminosity function). In our sample (see Table 12 and Figure 8) the average host is $M_V(L^*) = -20.9$. Moreover, about half by number of the field galaxies would be expected, in a volume limited sample, to lie within a magnitude of the lower limit cutoff of the Schechter luminosity function (which may be fainter than $M_V(L^*) = -17$). Thus, if the host galaxies were distributed with a Schechter luminosity function, we would have expected that about half of the hosts in our sample would be fainter than $M_V(L^*) = -18$ and therefore undetectable on the HST images. This is clearly not the case.

By comparing the 2-D model magnitudes of Table 12 and Figure 8 with the results expected from a Schechter luminosity function, we conclude that, on average, the host galaxies of the luminous quasars in our sample are about 2.2 magnitudes more luminous than typical field galaxies.

10.3. Previous Analyses

The conclusions presented in this summary paper are different in emphasis from the conclusions in our first two studies (see Papers I and II). In our earlier work, we discussed images of eight quasars (all are included in the sample in the current work), and reported the definitive detection of three host galaxies. We also presented limits on the brightnesses of the hosts for the other five quasars. The images presented in this paper show that more than half of the entire sample of 20 quasars has obvious hosts, and there is solid evidence that most, if not all, of the remaining quasars also have host galaxies.

The initial caution that we expressed regarding the detection of host galaxies was due to a combination of the unlucky observing sequence and our conservatism about interpreting the complex *HST* images. The unprocessed *HST* data (see Figure 1) are sufficient to show, even to the untrained eye, that at least nine of the 20 quasars in our sample have obvious hosts or diffuse environments. These obvious examples include the three spiral hosts (PG 0052+251, 1309+355, and PG 1402+261), the three quasars "caught in the act" (0316−346, PG 1012+008, and PKS 2349−014), and three prominent ellipticals (PHL 909, HE 1029−140, and 3C 273). None of these quasars were among the first four objects (PG 0953+414, PG 1116+215, PG 1202+281, and PG 1307+085) observed (Paper I), and only one (3C 273, whose host we described in paper II together with the original observations) belonged to the sample of eight quasars (Paper II). With a probability of 9/20 per observation of observing an obvious host, it was simply bad luck (about a 5% chance)

that only one of the initial eight quasars studied in Paper I and Paper II had an obvious host.

Given the repaired, but still complex and temporally variable PSF of the *HST*, we presented our results (see Table 3 of Paper II) for the non-detections as a morphology-dependent limit on the brightness of the host galaxy. Spiral galaxies, with their azimuthal variation in brightness and regions of high surface brightness, could be seen to considerably fainter total brightnesses (more than a magnitude) than large, extended ellipticals with their smooth, regular profiles. As we have gained experience with the data, we have become more confident of our ability to judge the reality of low surface brightness features. Most importantly, during *HST* Observation Cycle 5, we obtained additional images of PG 0953+414, a quasar analyzed in Paper I which showed very faint, extended nebulosity that was not centered on the quasar. The Cycle 5 observations were obtained at a different roll angle than those described in Paper I; the new observations confirmed the reality of the diffuse features (the nebulosity remained fixed in the sky when the telescope was rotated). The observations of PG 0953+414 suggested that some of the faint features were real that we had initially worried could be PSF features.

In retrospect, it appears that the vast majority of our initial observations consisted of quasars whose hosts had smooth, regular profiles. Comparing our adopted brightnesses of the hosts (Table 12) with the brightness limits set in our earlier work by simulations (Table 3 in Paper II), we find that the appropriate brightnesses limits (those for smooth ellipticals like 5d and 5e of Figure 5 of Paper II) were reasonably accurate. The detected brightnesses reported in Table 12 of this paper range from considerably fainter than the Paper II limit (*e.g.,* PG 0953+414) to slightly brighter than the limit (*e.g.,* 3C 323.1). Since the morphology of the hosts of the initial quasars was biased towards one type of galaxy (the least favorable type as far as detectability), it was not accurate, as we did, to quote a

detection limit that was the average of all the galaxy types.

10.4. Close Companions

The *HST* images frequently reveal companion galaxies that are projected very close to the quasar, in some cases as close as $1''$ or $2''$. Table 6 shows 20 galaxy companions that are projected closer than 25 kpc to the center-of-light of a quasar and brighter than $M_($F606W$) = -16.4$. Altogether, 13 of the 20 quasars in our sample have close companions that satisfy the requirements for inclusion in Table 6. The amplitude for the quasar-galaxy correlation function determined from our data is 3.8 ± 0.8 times larger than the galaxy-galaxy correlation function (Fisher et al. 1996).

10.5. Ground-based Studies

Our results for individual objects are compared in Section 8 with the results from previous ground-based observations. In general, the agreement with ground-based observations is satisfactory, but not as precise as we would have hoped. The most straightforward comparison is with the results of Véron-Cetty & Woltjer (1990) in annular regions well separated from the quasar. Even in this case, our *HST* magnitudes are, on average, 0.4 mag fainter than the Véron-Cetty & Woltjer values. Our 2-D model estimates for the total luminosities are, on average, 0.8 magnitude fainter than their 1-D model fits. The average discrepancy between our results and Dunlop et al. (1993) is 1.0 ± 0.6 mag (our results are generally brighter than Dunlop et al.), and the average discrepancy between our results and McLeod & Rieke is 0.4 ± 0.2 mag.

10.6. Future Work

Some pre-HST theoretical analyses (e. g.,by Falle, Perry, and Dyson 1981, Weymann et al. 1982, Begelman 1985, and Chang, Schiano, and Wolfe 1987) have suggested that luminous quasars may have dramatic effects on their environments via the radiation or hot winds that the quasar emits. The continuum images shown in this paper do not provide obvious evidence for the effects of the quasar on the host environment. In fact, the three spiral host galaxies and several of the host ellipticals appear remarkably normal. Broad band colors and spectroscopic observations are required in order to determine more sensitively whether the host galaxy is really oblivious to the presence of the luminous quasar in its center. The theoretical modeling can now be made more specific and compared with the results of the HST observations for individual host galaxies. These studies will be important in constraining the time scale of the quasar phenomenon and the isotropy of the quasar emissions. If a quasar shines brightly for only a short period of time or if the emission is highly anisotropic, then the lack of a dramatic effect of the bright AGN on the surrounding medium may be more easily understood.

One of the key results that is apparent in Figures 1 and 2 is the detailed evidence for gravitational interactions among the systems “caught in the act” (0316−346, PG 1012+008, and PKS 2349−014). Dynamical modeling of these systems could provide insights into the processes involved in the formation and fueling of quasars.

HST images provide detailed quantitative information about the environments in which the quasar phenomenon occurs. We hope to increase our sample in the future and to obtain color information about the objects discussed here. It should be feasible to obtain spectra of the brightest H II regions in the spiral hosts of PG 0052+251, PG 1309+355, and PG 1402+261. Detailed comparisons between the *HST* and ground-based images will be very informative.

We are grateful to P. Crane, M. Fall, O. Gnedin, K. Kellermann, K. McLeod, J. Miller, G. Neugebauer, M. Rees, G. Rieke, and M. Strauss for valuable discussions, comments, and suggestions. J. Krist and C. Burrows constructed the four stellar PSFs used in this work; we are grateful to them for their skill and generosity in providing these data. We would like to thank Digital Equipment Corporation for providing the DEC4000 AXP Model 610 system used for the computationally intensive parts of this project. This work was supported in part by NASA contract NAG5-1618, NAG5-3259, NASA grant number NAGW-4452 and grant number GO-5343 from the Space Telescope Science Institute, which is operated by the Association of Universities for Research in Astronomy, Incorporated, under NASA contract NAS5-26555. We have used the NASA/IPAC Extragalactic Database (NED), operated by the Jet Propulsion Laboratory, Caltech, under contract with NASA, and NASA's Astrophysics Data System Abstract Service (ADS).

REFERENCES

Bahcall, N., & Bahcall, J.N. 1970, PASP, 82, 1276

Bahcall, J. N., et al. 1993, ApJS, 87, 1

Bahcall, J. N., Kirhakos, S., & Schneider, D. P. 1994, ApJ, 435, L11 (Paper I)

Bahcall, J. N., Kirhakos, S., & Schneider, D. P. 1995a, ApJ, 450, 486 (Paper II)

Bahcall, J. N., Kirhakos, S., & Schneider, D. P. 1995b, ApJ, 447, L1 (Paper III)

Bahcall, J. N., Kirhakos, S., & Schneider, D. P. 1995c, ApJ, 454, L175 (Erratum)

Bahcall, J. N., Kirhakos, S., & Schneider, D. P. 1996, ApJ, 457, 557

Bahcall, J. N., Kirhakos, S., Schneider, D. P., Davis, R.J., Muxlow, T. W. B., Garrington, S. T., Conway, R. G., & Unwin, S.C. 1995, ApJ, 452, L91 (Paper IV)

Begelman, M. C. 1985, ApJ, 297. 492

Boroson, T. A., Person, S. E., & Oke, J. B. 1985, ApJ,293, 120

Bruzual A., G., & Charlot, S. 1993, ApJ, 405, 538

Burrows, C. J. 1994, Hubble Space Telescope Wide Field and Planetary Camera 2 Instrument Handbook, Version 2.0 (Baltimore: Space Telescope Science Institute)

Chang, C. A., Schiano, A. V. R., and Wolfe, A. M. 1987, ApJ, 322, 180

de Vaucouleurs, G. 1948, Ann. d'Ap., 11, 247

Disney, M.J., Boyce, P.J., Blades, J.C., Boksenberg, A., Crane,P., Deharveng, J.M., Macchetto, F., Mackay, C.D., Sparks, W.B., & Phillips, S. 1995, Nature, 376, 150

Dunlop, J. S., Taylor, G. L., Hughes, D. H., & Robson, E. I. 1993, MNRAS, 264, 455

Efstathiou, G., Ellis, R. S., & Peterson, B. A. 1988, MNRAS, 232, 431

Falle, S. A. E. G., Perry, J. J., and Dyson, J. E. 1981, MNRAS, 195, 397

Fisher, K. B., Bahcall, J. N., Kirhakos, S., & Schneider, D. P. 1996, ApJ, in press

Gehren, T., Fried, J., Wehinger, P.A., & Wyckoff, S. 1984, ApJ, 278, 11

Fukugita, M., Shimasaku, K., & Ichikawa, T. 1995, PASP, 107, 945

Heckman, T. M., Bothun, G. D., Balick, B., & Smith, E. P., 1984, AJ89, 958

Hickson, P., & Hutchings, J. B. 1987, ApJ, 312, 518

Hoessel, J. G., & Schneider, D. P. 1985, AJ, 90, 1648

Holtzman, J. A., et al. 1995a, PASP, 107, 156

Holtzman, J. A., et al. 1995b, PASP, 107, 1065

Hutchings, J.B. 1987, ApJ, 320, 122

Hutchings, J.B., Crampton, D., Campbell, B., Gower,A.C., & Morris, S.C. 1982, ApJ, 262, 48

Hutchings, J. B., Janson, T., & Neff, S. G. 1989, ApJ, 342, 660

Hutchings, J. B. & Neff, S. G. 1992, AJ, 104, 1

Hutchings, J. B. & Morris, S. 1995, AJ, 109, 1541

Hutchings, J. B. Holtzman, J., Sparks, W.B., Morris, S.C., Hanisch, R.J., & Mo, J. 1994, ApJ, 429, L1

Jannuzi, B.T., et al. 1997, in preparation

Kellermann, K.I., Sramek, R.A., Schmidt, M., Green, R.F., & Shaffer, D.B., 1994, AJ, 108, 1163.

Kirshner, R. F., Oemler, A., Schechter, P. L., & Shectman, S. A. 1983, AJ, 88, 1285

Krist, J., & Burrows, C. 1994, WFPC2 Instrument Science Report 94-01 (Baltimore: Space Telescope Science Institute)

Krist, J., & Burrows, C. 1996, http://www.sns.ias.edu/~jnb (go to HST Images).

Kristian, J. 1973, ApJ, 179, L61

Malkan, M.A., Margon,B., & Chanan, G.A. 1984, ApJ, 280, 66

McLeod, K. K., 1996, private communication.

McLeod, K. K., & Rieke, G. H. 1994a, ApJ, 420, 58

McLeod, K. K., & Rieke, G. H. 1994b, ApJ, 431, 137

McLeod, K. K., & Rieke, G. H. 1995, ApJ, 454, L77

Montgomery, K. A., Marschall, L. A., & Janes, K. A. 1993, AJ, 106, 181

Neugebauer, G., Matthews, K., & Armus, L. 1995, ApJ, 455,L123

Postman, M., & Lauer, T. R. 1995, ApJ, 440,28

Romanishin, W., & Hintzen, P. 1989, ApJ, 341, 41

Sandage, A. 1961, The Hubble Atlas of Galaxies, Publication 618, Carnegie Institution of Washington, Washington, D.C.

Schechter, P. 1976, ApJ, 203, 297

Schweizer, F. 1996, AJ, 111, 109

Smith, E. P., Heckman, T. M., Bothun, G. D., Romanishin, W., & Balick, B. 1986, ApJ, 306, 64

Stockton, A. 1978, ApJ, 223, 747

Stockton, A. 1980 IAU simposium 92, page 89

Stockton, A. 1982, ApJ, 257, 33

Stockton, A., & MacKenty, J. W. 1987, ApJ, 316, 584

Stockton, A., Ridgway, S., & Kellogg, M. 1996, in preparation

Trauger, J. T., et al. 1994, ApJ, 435, L3

Toomre, A., 1995 (private communication)

Tyson, J. A., Baum, W. A., & Kreidl, T., 1982 ApJ, 257, L1

Véron-Cetty, M. P. & Woltjer, J. 1990, A&A, 236,69,

Véron-Cetty, M. P., & Véron, P. 1991, A Catalogue of Quasars and Active Nuclei (Fifth Edition), ESO Scientific Report No. 10, European Southern Observatory, Garching bei Munchen, Germany

Véron-Cetty, M. P., & Véron, P. 1996, A Catalogue of Quasars and Active Nuclei (Seventh Edition), ESO Scientific Report No. 17, European Southern Observatory, Garching bei Munchen, Germany

Weymann, R. J., Scott, J. S., Schiano, A. V. R., and Christiansen, W. A. ApJ, 262, 497

Wisotzki L. 1994, A&A, 292, 45

Wisotzki L., Hagen, H., Hopp U., & Reimer D. 1991, Physics of Active Galactic Nuclei, eds. W.J. Duschl, S.J. Wagner, Springer-Verlag, p.438

Wyckoff, S. Wehinger, P. A., & Gehren T., 1981 ApJ, 247, 750

Yee, H.K.C. 1987, AJ, 94, 1461

This manuscript was prepared with the AAS LaTeX macros v4.0.

FIGURE CAPTIONS

Fig. 1.— A $23'' \times 23''$ WF image of each one of the twenty luminous nearby quasars in our sample. A blue field star, MMJ 6490, is also shown for comparison (first panel). These images were obtained using the *HST* WF3 and the F606W filter. The exposure times are 1400 s or 1100 sec (see Table 1). Cosmic ray subtraction and pipeline STScI flatfielding are the only processing performed on the *HST* images shown here.

Fig. 2.— Same set of quasars and comparison blue star as shown in Figure 1, but in this case the best-fit PSF for a standard blue star has been subtracted.

Fig. 3.— The difference between using a PSF for a blue star and a PSF for a red star. The image in panel a) was obtained by subtracting a PSF of MMJ 6481 ($B-V = -0.07$) and the image in panel b) was obtained by subtracting a PSF of F141 ($B-V = 1.11$). The measured host galaxy magnitudes are the same within 0.1 mag for the two subtractions shown.

Fig. 4.— This figure is a close-up, at two different contrast levels, of a peculiar object $12''$ east of the quasar NAB 0205+02. Stockton and Mackenty (1987) first noticed it for being visible in their [O III] image, but not in the continuum. The *HST* image shown is $8'' \times 8''$, and the exposure time is 1900 sec. Because of its morphological peculiarity, we refer to this object as the "Barbell".

Fig. 5.— An expanded view of this spectacular merger of PG 1012+008, which was "caught in the act". The exposure time is 1400 sec.

Fig. 6.— PSF subtracted image of the quasar PG 1309+355 showing details in the inner region of the host. Tightly wrapped spiral arms surround the nucleus. The exposure time is 1400 sec.

Fig. 7.— H II regions in the spiral host of PG 1402+261. The H II regions listed in Table 11 are identified in the upper panel. The bar and probable inner ring are visible in the lower contrast image reproduced in the lower panel.

Fig. 8.— Absolute visual magnitude of the host galaxies versus the absolute visual magnitude of the quasars. The magnitudes and morphologies of the host galaxies are determined using two-dimensional fits (cf. the summary in Table 12); the absolute magnitudes of the quasars are taken from Table 1. The diagonal line represents the average detection limit of smooth ellipticals in an idealized sample; see the discussion in § 10.2. For two of the quasars, PHL 909 and 3C 323.1, the symbols overlap at $M_V(\text{host}) = -21.2$ and $M_V(\text{QSO}) = -22.9$.

Table 1. Quasar Sample

Object	Date	Time (s)	sky level (e^- pix^{-1} s^{-1})	z	kpc arcsec^{-1}	V	M_V(QSO)[a]	Radio Loud	FOS[b]
PG 0052+251	05 Dec 94	1400	0.114	0.155	1.75	15.4	−23.0		
PHL 909	17 Oct 94	1400	0.136	0.171	1.88	15.7	−22.9		
NAB 0205+02	26 Oct 94	1400	0.139	0.155	1.75	15.4	−23.0		
0316−346	20 Nov 94	1400	0.075	0.265	2.55	15.1	−24.5		
PG 0923+201	23 Mar 95	1400	0.136	0.190	2.04	15.8	−23.1		
PG 0953+414	03 Feb 94	1100	0.110	0.239	2.38	15.3	−24.1		K
PKS 1004+130	26 Feb 95	1400	0.150	0.240	2.39	15.2	−24.2	X	
PG 1012+008	25 Feb 95	1400	0.129	0.185	2.00	15.6	−23.2		
HE 1029−140	06 Feb 95	1400	0.100	0.086	1.22	13.9	−23.2		
PG 1116+215	08 Feb 94	1100	0.128	0.177	1.93	14.7	−24.0		K,O
PG 1202+281	08 Feb 94	1100	0.116	0.165	1.83	15.6	−23.0		K
3C 273	05 Jun 94	1100	0.151	0.158	1.78	12.9	−25.6	X	K,O
PKS 1302−102	09 Jun 94	1100	0.136	0.286	2.67	15.2	−24.6	X	K
PG 1307+085	05 Apr 94	1400	0.129	0.155	1.75	15.1	−23.3		
PG 1309+355	26 Mar 95	1400	0.088	0.184	1.99	15.6	−23.2		O
PG 1402+261	07 Mar 95	1400	0.089	0.164	2.13	15.5	−23.0		
PG 1444+407	27 Jun 94	1100	0.071	0.267	2.56	15.7	−23.9		K,O
3C 323.1	09 Jun 94	1100	0.082	0.266	2.55	16.7	−22.9	X	
PKS 2135−147	15 Aug 94	1400	0.174	0.200	2.11	15.5	−23.5	X	O
PKS 2349−014	18 Sep 94	1400	0.161	0.173	1.90	15.3	−23.4	X	

[a] Computed for $\Omega_0 = 1.0$ and $H_0 = 100$ km s^{-1}Mpc^{-1}. In this cosmology, brightest cluster galaxies have $M_V \approx -22.0$ (Hoessel & Schneider 1985; Postman & Lauer 1995) and the characteristic (Schechter-) magnitude for field galaxies is $M_V^* = -20.5$ (Schechter 1976; Kirshner et al. 1983; Efstathiou, Ellis, & Peterson 1988).

[b] K = *HST* Quasar Absorption Line Key Project; O = Other FOS observations.

Table 2. Size and Morphology of Host Galaxies

Object	Major Diameter $''$	kpc	Isophote (F606W) mag arcsec^{-2}	Morphology
PG 0052+251	20	35	25.1	Sb
PHL 909	19	36	24.7	E4
NAB 0205+02	9	16	25.0	S0?
0316−346	17	43	25.6	Complex, interaction
PG 0923+201	13	27	24.8	E1
PG 0953+414	11	26	25.8	Faint, tail?
PKS 1004+130	15	36	25.0	E2
PG 1012+008	18	36	25.0	Interacting galaxies
HE 1029−140	40	49	26.0	E1
PG 1116+215	14	27	25.1	E2
PG 1202+281	10	18	24.7	E1, bright companion
3C 273	29	52	25.4	E4
PKS 1302−102	15	40	25.2	E4 (?) two close companions
PG 1307+085	9	16	24.6	Faint E1 (?)
PG 1309+355	18	36	25.7	Sab
PG 1402+261	14	30	25.6	SBb
PG 1444+407	10	26	25.2	E1 (?)
3C 323.1	11	28	25.1	E3 (?) (bright companion)
PKS 2135−147	15	32	24.8	E1 (companions)
PKS 2349−014	21	40	24.5	Complex, interacting

Table 3. Aperture Magnitudes for Host Galaxies

Object	inner radius ($''$)	outer radius ($''$)	aperture photometry m_{F606}	M_{F606}	$(F606-V)^a$	aperture photometry M_V
PG 0052+251	1.0	10.0	17.1	−21.3	−0.31	−21.0
PHL 909	1.0	10.0	17.5	−21.1	−0.41	−20.7
NAB 0205+02	1.0	4.5	19.5	−18.9	−0.31	−18.6
0316−346	1.0	11.5	18.2	−21.4	−0.47	−20.9
PG 0923+201	1.0	6.5	18.3	−20.6	−0.42	−20.2
PG 0953+414	1.0	5.5	19.1	−20.3	−0.38	−19.9
PKS 1004+130	1.0	7.5	17.7	−21.7	−0.48	−21.2
PG 1012+008	1.0	4.5	17.8	−21.0	−0.39	−20.6
HE 1029−140	1.5	20.0	16.5	−20.6	−0.35	−20.2
PG 1116+215	1.0	8.0	17.7	−21.0	−0.41	−20.6
PG 1202+281	1.0	5.0	18.6	−20.0	−0.40	−19.6
3C 273	2.0	15.0	16.6	−21.9	−0.40	−21.5
PKS 1302−102	1.0	7.5	18.4	−21.4	−0.50	−20.9
PG 1307+085	1.0	4.5	18.7	−19.7	−0.37	−19.3
PG 1309+355	1.0	9.0	17.4	−21.4	−0.35	−21.0
PG 1402+261	1.0	7.5	18.1	−20.4	−0.30	−20.1
PG 1444+407	1.0	5.0	18.8	−20.8	−0.47	−20.3
3C 323.1	1.0	5.5	18.9	−20.7	−0.47	−20.2
PKS 2135−147	1.0	7.5	18.1	−20.9	−0.45	−20.4
PKS 2349−014	1.0	12.0	16.7	−22.0	−0.41	−21.6

[a] Fukugita et al. (1995)

Table 4. Model Fits to Stellar Quasar plus Host Galaxy

	One−Dimensional				Two−Dim ensional			
	GdV		Exp. Disk		GdV		Exp. Disk	
Object	m_{F606}	r($''$)[a]	m_{F606}	r($''$)[b]	m_{F606}	r($''$)[a]	m_{F606}	r($''$)[b]
PG 0052+251	16.1	4.7	16.8	1.4	16.7	1.8	17.2	1.3
PHL 909	16.7	2.5	17.4	1.0	17.2	2.3	17.6	1.5
NAB 0205+02	18.0	0.6	18.7	0.6	18.4	0.7	19.0	0.7
0316−346	17.2	3.4	18.0	1.1	17.8	2.1	18.3	1.2
PG 0923+201	17.3	2.5	18.0	1.0	17.5	2.9	18.2	1.3
PG 0953+414	17.9	2.3	18.5	1.1	18.2	1.8	18.8	1.1
PKS 1004+130	16.7	1.6	17.3	0.9	16.9	1.2	17.5	1.0
PG 1012+008	16.3	6.2	17.3	1.4	17.0	3.4	17.7	1.6
HE 1029−140	15.9	2.8	16.4	1.5	16.2	3.2	16.7	1.9
PG 1116+215	16.6	1.9	17.3	1.0	16.9	1.4	17.5	1.2
PG 1202+281	17.4	1.5	18.1	0.9	17.7	1.4	18.3	1.0
3C 273	15.6	2.3	16.2	1.3	16.0	3.7	16.7	1.6
PKS 1302−102	17.1	2.6	17.8	1.1	17.7	1.4	18.2	1.1
PG 1307+085	17.4	1.8	18.1	0.9	17.8	1.3	18.4	1.0
PG 1309+355	16.4	2.8	17.1	1.1	16.8	2.0	17.3	1.2
PG 1402+261	16.9	2.2	17.6	1.0	17.6	1.5	18.3	1.6
PG 1444+407	17.6	1.3	18.2	1.0	17.8	1.3	18.4	1.0
3C 323.1	17.8	1.4	18.4	0.9	18.1	1.6	18.7	1.0
PKS 2135−147	17.2	2.0	17.8	1.1	17.4	2.6	18.0	1.3
PKS 2349−014	15.9	5.6	16.6	1.6	16.2	4.8	16.8	2.5

[a] Effective radius.

[b] Exponential scale length.

Table 5. Absolute Visual Magnitudes for Quasar Host Galaxies

	One−Dimensional		Two−Dimensional	
Object	M_V(1-D)	best model	M_V(2-D)	best model
PG 0052+251	−21.3	Disk	−20.9	Disk
PHL 909	−21.5	GdV	−21.0	GdV
NAB 0205+02	−19.4	Disk	−19.1	Disk
0316−346	−21.1	Disk	−20.8	Disk
PG 0923+201	−21.2	GdV	−21.0	GdV
PG 0953+414	−20.5	Disk	−20.2	Disk
PKS 1004+130	−22.5	GdV	−22.0	GdV
PG 1012+008	−22.1	GdV	−20.7	Disk
HE 1029−140	−20.8	GdV	−20.5	GdV
PG 1116+215	−21.7	GdV	−21.4	GdV
PG 1202+281	−20.8	GdV	−20.5	GdV
3C 273	−22.5	GdV	−22.1	GdV
PKS 1302−102	−21.5	Disk	−21.1	Disk
PG 1307+085	−20.6	GdV	−20.2	Disk
PG 1309+355	−21.3	Disk	−21.1	Disk
PG 1402+261	−20.6	Disk	−19.9	Disk
PG 1444+407	−20.9	Disk	−20.5	Disk
3C 323.1	−21.3	GdV	−21.0	GdV
PKS 2135−147	−21.3	GdV	−21.1	GdV
PKS 2349−014	−22.4	GdV	−22.1	GdV

Table 6: Galaxy Companions Brighter than $M_{(\mathrm{F606W})} = --16.5$ within 25 kpc of the Quasar

Quasar	Number of Companions	Distances ″	Distances kpc	Magnitudes m_{F606}	Magnitudes M_{F606}
PG 0052+251	1	14.1	24.6	18.8	−19.6
PHL 909	1	12.5	23.5	21.4	−17.2
NAB 0205+02	1	8.3	14.5	20.0	−18.4
PG 0923+201	2	10.9	22.2	19.5	−19.4
		11.0	22.5	18.0	−20.9
PG 0953+414	1	8.2	19.6	22.7	−16.7
PG 1012+00	2	3.3	6.7	17.6	−21.2
		6.8	13.7	19.0	−19.8
PG 1116+215	1	12.3	23.8	19.3	−19.4
PG 1202+281	3	5.2	9.5	18.9	−19.7
		8.4	15.3	21.5	−17.1
		9.6	17.5	21.3	−17.3
PKS 1302−102	2	1.1	2.9	20.3	−19.5
		2.3	6.2	21.5	−18.3
HE 1029+140[a]	1	4.1	5.0	20.7	−16.4
3C 323.1	1	2.7	6.9	20.6	−19.0
PKS 2135−147	2	1.9	3.9	19.5	−19.5
		5.5	11.7	19.7	−19.3
PKS 2349−014	2	1.9	3.5	20.8	−17.9
		11.6	22.0	21.4	−17.3

[a] Absolute magnitude of the close companion is 0.1 mag fainter than the assumed limiting magnitude.

Table 7. Comparison with results of Véron-Cetty & Woltjer (1990)

Object	m_i^a	$M_{V(i)}^a$	M_{F606}^b	$M_{V(F606)}^b$	$M_V^a(model)$	$M_{V(F606)}^b(2-\mathrm{D})$
	12.5 kpc — 25 kpc					
PKS 1302−102	19.5	−20.3	−20.4	−20.0	−22.0	−21.1
PKS 2135−147	18.9	−19.9	−19.9	−19.4	−22.2	−21.1
PKS 2349−014	17.6	−20.7	−20.8	−20.4	−22.5	−22.1

[a] Véron-Cetty & Woltjer (1990)

[b] *HST* results, this paper

Table 8. Annular Magnitudes. $F606$ magnitudes of host galaxies measured in an annulus between radii of 6 kpc and 12 kpc for $H_0 = 100$ km s^{-1}Mpc^{-1}, $\Omega_0 = 1.0$. (This radii corresponds approximately to 12.5 kpc and 25 kpc for $H_0 = 50$ km s^{-1}Mpc^{-1}, $\Omega_0 = 0.0$)

Object	$r_1^a('')$	$r_2^b('')$	m_{F606}	M_{F606}	M_V
PG 0052+251	3.43	6.86	18.3	−20.1	− 19.8
PHL 909	3.19	6.38	18.8	−19.8	− 19.4
NAB 0205+02	3.43	6.86	20.7	−17.7	− 17.4
0316−346	2.80	4.71	19.8	−19.8	− 19.3
PG 0923+201	2.96	5.91	19.3	−19.6	− 19.2
PG 0953+414	2.52	5.04	20.1	−19.3	− 18.9
PKS 1004+130	2.51	5.02	18.9	−20.5	− 20.0
PG 1012+008	3.00	6.00	18.1	−20.7	− 20.3
HE 1029−140	5.56	11.11	18.0	−19.1	− 18.7
PG 1116+215	3.11	6.22	19.0	−19.7	− 19.3
PG 1202+281	3.28	6.56	19.9	−18.8	− 18.4
3C 273	3.37	6.74	17.8	−20.7	− 20.3
PKS 1302−102	2.25	4.49	19.4	−20.4	− 19.9
PG 1307+085	3.43	6.86	19.9	−18.5	− 18.1
PG 1309+355	3.02	6.03	18.7	−20.1	− 19.7
PG 1402+261	3.28	6.56	19.5	−19.0	− 18.7
PG 1444+407	2.34	4.69	19.7	−19.9	− 19.4
3C 323.1	2.35	4.71	19.9	−19.7	− 19.2
PKS 2135−147	2.84	5.69	19.1	−19.9	− 19.4
PKS 2349−014	3.16	6.32	17.9	−20.8	− 20.4

[a] inner radius = 6 kpc

[b] outer radius = 12 kpc

Table 9. Comparison between absolute V magnitudes for quasar host galaxies expected from K-band and from $HST - F606W$ measurements

Object	K^{a}_{gal}	M_K	$(V-K)^b$	$M_{V(K)}$	$M_{V(F606)}(2-\mathrm{D})^c$	ΔM_V
PG 0052+251	15.14	−23.3	3.90	−19.4	−20.9	1.5
PHL 909	14.40	−24.2	3.95	−20.3	−21.0	0.7
PG 0923+201	14.95	−23.9	4.00	−19.9	−21.0	1.1
PG 0953+414	15.28	−24.1	4.20	−19.9	−20.2	0.3
PKS 1004+13	15.12	−24.3	4.20	−20.1	−22.0	1.9
PG 1012+00	13.94	−24.9	4.00	−20.9	−20.7	−0.2
PKS 2135−147	14.75	−24.2	4.10	−20.1	−21.1	1.0
PKS 2349−014	13.98	−24.7	3.95	−20.8	−22.1	1.3

[a] Dunlop et al. 1993.

[b] $(V-K)$ for elliptical galaxy from Bruzual & Charlot (1993).

[c] This work (derived from two-dimensional galaxy model fitting).

Table 10. Comparison between absolute V magnitudes for quasar host galaxies expected from H-band and from HST-F606W measurements

Object	H^{a}_{gal}	$(V-H)^{b}_{normal}$	$M_{V(H)}$	$M_{V(F606)}$(2-D)[c]	ΔM_V
PG 0052+251	14.46	3.16	−20.8	−20.9	0.1
PG 0923+201	14.86	3.22	−20.8	−21.0	0.2
PG 0953+414	15.38	3.32	−20.7	−20.2	−0.5
PKS 1004+130	14.86	3.32	−21.2	−22.0	0.8
PG 1012+008	14.02	3.21	−21.6	−20.7	−0.9
PG 1116+215	13.97	3.20	−21.6	−21.4	−0.2
PG 1202+281	15.07	3.18	−20.3	−20.5	0.2
3C 273	13.01	3.17	−22.3	−22.1	−0.2
PKS 1302−102	14.79	3.47	−21.5	−21.1	−0.4
PG 1307+085	15.24	3.16	−20.0	−20.2	0.2
PG 1309+355	14.55	3.21	−21.0	−21.1	0.1
PG 1402+261	14.95	3.18	−20.4	−19.9	−0.5
PG 1444+407	15.19	3.42	−21.0	−20.5	−0.5
3C 323.1	14.80	3.42	−21.4	−21.0	−0.4

[a] McLeod & Rieke (1994b).

[b] McLeod & Rieke (1995).

[c] This work (derived from two-dimensional galaxy model fitting.)

Table 11. H II Regions in the Host Galaxy of PG 1402+261

Region	m_{F606W}	d ($''$)	$\Delta\alpha$ ($''$)	$\Delta\delta$ ($''$)
a	23.7	2.8	−0.3	2.8
b	24.3	2.9	−1.5	2.5
c	25.3	2.9	−2.1	2.0
d	25.6	3.5	−3.3	1.3
e	25.5	4.6	−4.5	−0.9
f	26.2	4.8	−4.5	−1.8
g	26.2	5.0	−4.2	−2.8
h	25.9	5.3	−3.8	−3.7
i	25.6	4.1	−1.1	4.0
j	25.2	4.0	−2.7	3.0

Table 12. Summary of Magnitudes and Morphology for Quasar Host Galaxies

			Two−Dimensional		
Object	z	m_{606}(2-D)	M_V(2-D)	ϙlhead$r('')^a$	Morphology
PG 0052+251	0.155	17.2	−20.9	1.3	Sb
PHL 909	0.171	17.2	−21.0	2.3	E4
NAB 0205+02	0.155	19.0	−19.1	0.7	S0?
0316−346	0.265	18.3	−20.8	1.2	Inter.
PG 0923+201	0.190	17.5	−21.0	2.9	E1
PG 0953+414	0.239	18.8	−20.2	1.1	?
PKS 1004+130	0.240	16.9	−22.0	1.2	E2
PG 1012+008	0.185	17.7	−20.7	1.6	Inter.
HE 1029−140	0.086	16.2	−20.5	3.2	E1
PG 1116+215	0.177	16.9	−21.4	1.4	E2
PG 1202+281	0.165	17.7	−20.5	1.4	E1
3C 273	0.158	16.0	−22.1	3.7	E4
PKS 1302−102	0.286	18.2	−21.1	1.1	E4?
PG 1307+085	0.155	17.8	−20.2	1.3	E1?
PG 1309+355	0.184	17.3	−21.1	1.2	Sab
PG 1402+261	0.164	18.3	−19.9	1.6	SBb
PG 1444+407	0.267	18.4	−20.5	1.0	E1?
3C 323.1	0.266	18.1	−21.0	1.6	E3?
PKS 2135−147	0.200	17.4	−21.1	2.6	E1
PKS 2349−014	0.173	16.2	−22.1	4.8	Inter.

[a]Effective radius or exponential scale length.

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